DESIGN CRITERIA FOR BULB TYPE WING TIPS

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DESIGN CRITERIA FOR BULB TYPE WING TIPS

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PREFACE

Meaning of Symbols Used:

A.R.	Aspect ratio = $\frac{b^2}{S}$
b	Total wing span - feet
b'	Vortex span
c	Chord of wing
d	Maximum diameter of model in inches
C_D	Coefficient of total drag = $\frac{D}{qs}$
C_L	Coefficient of lift = $\frac{L}{qs}$
$C_{L_{max}}$	Coefficient of maximum lift
D'_o	Drag micrometer zero reading on control box (V = 0)
D'_M	Drag micrometer readings during model runs (V = 110 ft/sec)
D'_T	Drag micrometer readings during tare runs
ΔD_M	Increment of drag readings for models = $(D'_M - D'_o)$
ΔD_T	Increment of drag tare
D	Drag of model in pounds = $(\Delta D_M - \Delta D_T)$ x slope of drag calibration curve
h'_s	Static pressure in large section of tunnel upstream of the test section, millimeters of alcohol (spec. grav. 0.809)
l	Length of model - inches
L'_O	Lift zero micrometer reading on control box (V = 0)
L'_M	Lift micrometer readings during model runs (V = 110 ft/sec)
ΔL_M	Increment of lift readings for models = $(L'_M - L'_O)$

L	Lift of model in pounds = (ΔL_M) x slope of lift calibration curve
M'_O	Moment micrometer zero reading on control box ($V = 0$)
M'_M	Moment micrometer readings during model runs
ΔM_M	Increment of moment readings for models = $(M'_M - M'_O)$
q	Dynamic pressure in test section in vicinity of model - pounds per square foot = $\frac{\rho}{2} V^2$
S	Wing area in square feet
T	Local temperature of air in test section, degrees Rankine
T_o	Temperature of air under standard conditions @ $59^\circ F$
V	Velocity of air in test section - feet per second
α	Angle of attack of model with relative wind in degrees
ρ	Density of air in test section, slugs per cubic foot
ρ_o	Density of air under standard conditions = 0.002378 slugs per cubic foot
Γ	Circulation - ft^2/sec
$q_\bullet$	Tangential velocity - feet per second
w	Downwash velocity - feet per second

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I SUMMARY

Systematically chosen cylindrical bodies of revolution with various l/d ratios and contours were attached at the tips of Clark Y airfoil section wings and tested in the Thirty Inch Wind Tunnel at the Daniel Guggenheim School of Aeronautics, Georgia Institute of Technology, to determine the effect of bulb tips on the lift and drag characteristics of rectangular wings with aspect ratios of 4.83 and 6.84. Aspect ratios were the same in the tests for both the bulb and plain wing tips.

The experiment consisted of wind tunnel tests at aspect ratios 4.83 and 6.84 on seven bulb tip shapes. A plain semi-circular wing tip was also run for both aspect ratios. Additional runs were made to determine end plate effect of the bulb tips.

All the bulb tips tested gave higher values of drag coefficient for the wing than with the semi-circular tip. In every case the addition of the bulb tip reduced lift/drag ratio over the complete range of C_L.

The models were tested in an open throat with a constant wind velocity of seventy five miles per hour (110 feet per second), and the forces were measured by use of a three component electric strain gage balance system.

As a result of these tests it is possible to determine the relative effect of a given wing tip bulb on rectangular wings with aspect ratios between 4.83 and 6.84 which includes most aircraft of the lightplane class.

II INTRODUCTION

For a given spanwise load distribution on a wing the pressures nearing the tips tend to equalize for the upper and lower surfaces, i. e., the high negative pressure on the upper surface becomes more positive and the flow across the chord is deflected inboard against the lesser pressure. The high positive pressure on the lower surface decreases upon nearing the tip and the chordwise flow is deflected outboard. Of course the result is a decrease of the circulation approaching the tip. This reduced circulation is "spilled" off the trailing edge as small vortices conforming with bound vortex theory.[1] The fluid particles which flow over and under the wing near the tips are deflected laterally. When they meet again behind the wing their velocities no longer coincide. The particles which flowed above the wing have acquired a velocity component away from the tip, while those which flowed below the wing have a velocity component toward the tip. These lateral spanwise components form a potential motion, since they are produced by pressure differences. At the point beyond the wing where they meet again, they form an unstable motion which corresponds to a surface vortex. Since the streamline deflection on the wing depends on the lateral pressure drop, and since this in turn represents a decrease in lift or a circulation drop toward the wing tips, it is clear that the vortex in the surface of discontinuity corresponds to the circulation drop (bound vortex theory). If, therefore, the circulation around a wing becomes smaller near the tips, then vortices or corresponding circulation must pass off from the wing.[1]

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[1]Hermann Glauert, The Elements of Aerofoil and Airscrew Theory (Cambridge: University Press, 1947), pp. 128-170.

In order to be effective then, the bulb tip must minimize the changes in pressure approaching the tips, and maintain the given amount of circulation as near constant as possible.

A study of existing data on three dimensional airflow about airplane wing tips; spanwise lift and drag distributions and wing tip vortices; showed variations of flow at the tip which aircraft designers and aerodynamicists approximate with some uncertanity. These approximations assume circulation equal to zero at the tip, and a constant wing tip vortex span for all angles of attack. In the case of an end plated tip, however, the circulation at the tip is not zero,[2] and it is well known that the vortex span is less than the geometric span, approaching .80b for rectangular wings after rollup of all shed vortices has become complete at some point aft of the trailing edge.[3]

This investigation was initiated on the premise that a body of revolution attached at the wing tip would cause the tip vortex to form on it with a constant span and would increase the value of circulation (Γ) at the tip, thereby increasing the average circulation over the wing and therefore the total wing lift by the relation:

$$L = \rho V \Gamma_{av.} b'.$$

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[2] V. M. Falkner, The Design of Minimum Drag Tip Fins (British, Reports and Memoranda No. 2279, 1945), p. 13.

[3] Alan Y. Pope, "Basic Wing and Airfoil Theory," (mimeographed lecture notes, Daniel Guggenheim School of Aeronautics, Georgia Institute of Technology, Atlanta, 1948), p. 15:15.

Normally the tip vortex has a small diameter core of high velocity air.[4] It was primarily assumed that the bulb tip would partially eliminate this high velocity by expanding the diameter of the initial vortex, consequently reducing the drag of the wing by reducing the kinetic energy loss in the vortex.

First a theoretical analysis was used in attacking the problem. The wing tip bulb was treated as a classical cylinder in a uniform stream with a circulation about it, the value of the circulation being the average circulation across the wing or around the bound vortex system, which is:

$$\Gamma = \frac{L}{\rho V b'} .$$

It was assumed that the tangential velocity about the cylinder q_θ should be about equal to the downwash velocity ($w = \frac{\Gamma}{2b'}$) aft of the trailing edge, corresponding to uniform downwash along the wing span.

Then:

$$q_\theta = 2V' \sin\theta + \frac{\Gamma}{2\pi r}$$

where

V' = the component of the free stream velocity $\underline{V}$ normal to the cylinder.

Theoretical calculations produced bulb diameters too large for practical consideration due to the large frontal area that would be added,

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[4]A. Betz, The Vortex Theory and Its Significance in Aviation (U. S. National Advisory Committee for Aeronautics, Technical Memorandum No. 576, 1930), p. 4.

and this first approach to the problem was abandoned.

The experimental comparison of lift and drag for various bulb tips on rectangular wings was therefore undertaken to determine the effectiveness of the arrangement for the above functions.

III APPARATUS

An open throat test section was initially decided upon for this series of wind tunnel tests because it would give the desired results with the minimum number of corrections. It was also necessary to have access to the model for changing the angle of attack during the runs. With the open throat on the Thirty Inch Wind Tunnel it was possible to make complete runs without shutting down the tunnel. (See Figures 9 and 10.)

The effect of the support on the model and the model on the support was ignored; due to the comparative nature of the tests these factors were the same for all runs. Jet boundary effects, longitudinal static pressure gradient, and blocking effects are negligible because of the lack of test section walls. Flow divergence was calibrated and found to be negligible laterally, but an average of one half degree up in the vertical plane.

Models were constructed of mahogany and walnut. End plates were made from .064 thick 24 ST duraluminum. Attachment to the wing was made with two screws along the center line of the bulb tips. (See Figure 13.) All tips were carefully faired into the wing with modeling clay.

The forces were measured with a strain gauge balance system controlled by a Baldwin Southwark SR-4 Control Box and a selector box for switching to lift, drag, and moment readings.[5] (See Figure 12.) It was

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[5]Leslie R. Merritt, "The Development of a Strain Gage Balance System for the Thirty Inch Wind Tunnel at the Georgia School of Technology," (unpublished Master's thesis, Daniel Guggenheim School of Aeronautics, Georgia Institute of Technology, Atlanta, June, 1947).

necessary to take the moment micrometer readings in order to apply a correction factor to the drag micrometer readings.

Electrical energy for the balance system was supplied by a 6 volt dry cell battery.

At the outset it became necessary to place the control box in an isolated and suspended condition to eliminate the effects of tunnel vibration on the micrometer readings.

The wind tunnel was controlled by a radial type rheostat and a fine adjustment slide rheostat in series to set the tunnel velocity accurately.

Wind velocity was limited to seventy five miles per hour (110 feet per second) due to the unstable character of the flow in the jet above that speed and also excessive tunnel vibration caused by the motor armature being out of balance. A calibrated manometer reading static pressure in the large section of the tunnel upstream of the test section was used to read the wind velocity. (See Figure 12.)

All tips were tested at angles of attack from -3 to +13 degrees. Angles were set to an accuracy of 0.1 degree.

Due to the low Reynold's Number of the tests, particular attention was paid to the surface finish of the models, which was made very smooth.

IV PROCEDURE

Before any test runs were made with models mounted on the balance, a velocity calibration, flow angularity survey, and tare readings of the balance were made in the open throat test section in the vicinity of where the model would be mounted. Velocity and flow angularity surveys were made with a calibrated directional pitot tube (yawhead) which was moved across the throat in four inch increments. The average longitudinal velocity gradient across the tunnel was less than 1% or one foot per second, and the lateral velocity was negligible. The average vertical upflow was found to be one half degree.

The turbulence factor was determined by use of a four and one half inch turbulence sphere, and was found to be 1.3 using two screens in the large section of the wind tunnel upstream of the test section. This low turbulence factor is not too well substantiated due to the necessity of extrapolating the data, but makes no difference in the final results.

Static pressure in the vicinity of the model was constant and equal to atmospheric pressure throughout the section.

Preliminary test runs were made with the wing tips mounted on NACA 0018 symmetrical airfoil rectangular wings with three inch chords. After much difficulty and investigation the tests were discarded because curved lift curves developed. It was determined that the flow was separating on the top and lower surfaces of the models at low angles of attack at the test Reynold's Number of approximately 208,000. As the angle of attack was increased the separation on the lower surface decreased, disappearing at about +5 degrees. At this angle the slope of the lift curve increased sharply from 0.082 to 0.092 approximately.

Clark Y airfoils were then decided upon because of the flat lower surface. This flat surface, it was believed, would eliminate the lower surface separation experienced with the NACA 0018 symmetrical airfoil at angles of attack from -5 to +5 degrees. The Clark Y wings were satisfactory down to -4 degrees, but difficulty was again experienced at -6 degrees giving unsteady data at this setting. However, the investigation was not concerned with this low angle and as the Clark Y wings provided excellent data they were used for the experiments.

The balance system was found to be slightly out of line with the center line of the tunnel and this was corrected before runs were made.

In the test runs Clark Y models with tips were first mounted at zero relative angle of attack and control box zero readings of Lift (L'_o), Drag (D'_o), and Moment (M'_o) were taken. The tunnel was then started and the velocity in the test section stabilized at 110 feet per second by use of a manometer reading the static pressure (h'_s) in the large section of the tunnel upstream of the test section. By the calibration run, $V = 110$ feet per second in the test section was equivalent to $h'_s = 90.00$ millimeters of alcohol, specific gravity 0.809.

Maintaining a constant velocity in the test section, control box micrometer readings of the forces on the model were taken, i. e., lift, drag, and moment, at angle of attack from -3 to +13 degrees. The tunnel was then shut down and the zero readings taken again. Repeat zero readings coincided within experimental accuracy with the initial readings.

Tare runs were made with no model, only the balance and supports in the test section. The zero readings were taken as before for lift, drag, and moment with V = 0; with V = 110 feet per second, readings were again taken and recorded. The sting support was varied in length as it is when the model is in place and tests are being run.

Tares were found to be zero for lift and moment. Drag tares varied slightly with lengthening or shortening of the sting support.

Interference effects were the same for all runs with models in place, and were for that reason unimportant due to the comparative nature of the experiment.

It was necessary to calibrate the control box micrometer readings for conversion to pounds, for lift and drag.[6] The micrometer readings were plotted against applied loads on the balance system.

The slope of the calibration curves were found to be constant over the calibration range, and are as follows: (decade 4600)

Lift = 1.09 pounds/unit lift micrometer reading;

Drag = 0.440 pounds/(unit drag micrometer reading - 0.27 x unit moment micrometer reading).

Moment readings were used only to correct drag readings, and therefore need no further discussion for this thesis.

To convert the raw data into the actual lift and drag forces acting on the model, the tare was subtracted from the micrometer reading and the remainder multiplied by the slope of the respective strain gage calibration curve. This calculation produces forces in pounds. Lift and drag coefficients were the required data for this investigation; therefore the

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[6] _Ibid._

forces in pounds were divided by the wing area and dynamic pressure to get C_L and C_D. The coefficients obtained were plotted against angle of attack for both aspect ratios and are presented in Appendix II.

V RESULTS

Due to the complete absence of any previous experimental data on wing tip bulb applications, it was not possible to make any comparison with the present test results.

The tests were all run at a constant Reynold's Number of approximately 208,000 and the results are, therefore, effectively independent of Reynold's Number for purposes of comparison. However, the results presented in the appendices are only comparative and are not to be taken as being quantitative for other Reynold's Numbers. The values of lift and drag are not consistent with those obtained at the higher Reynold's Numbers since the critical Reynold's Number range has not been reached,[7] nor was it possible to exceed the test Reynold's Number due to limitations imposed by size and velocity in the small wind tunnel.

The following conclusions were derived from the tests:

1. All bulb tip configurations are less efficient than for the wing tip alone for rectangular wings. (See Figures 3 and 7.)
2. Optimum d is about 12 to 15 percent of tip length.
3. Optimum diameter of the bulb is approximately .25 c.
4. The optimum bulb tip gives an increase in total wing C_D of ΔC_D = .002 for C_L up to .75. (See Figures 2 and 6.)

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[7] Eastman N. Jacobs and Albert Sherman, Airfoil Section Characteristics as Affected by Variations of the Reynold's Number (U. S. National Advisory Committee for Aeronautics, Technical Report No. 586, 1937), p. 31.

5. Streamline form of the bulb tip is vital if optimum diameter is exceeded, as might be necessary in the case of a wing tip fuel tank; form appears to become less important as the optimum diameter is approached.
6. Bulb tips are superior to end plates at optimum d; inferior to end plates with greater d than optimum unless they are properly shaped. (See Figures 4 and 8.)
7. Changing the angle of attack of the bulb tip relative to the wing chord line increases drag and decreases L/D ratio.

The diameter that gave the highest L/D ratio of all the bulb tips was the 11/16 inch (d = 23% chord) one. (See Table I.) The L/D was still less for the NACA 0009 tip (d = 17% chord) and the NACA 0021 tip (d = 42% chord). Referring to the curves of L/D (Figures 3 and 7) an optimum value of d = 0.25 chord was obtained by interpolation.

The optimum diameter tip was formed by revolving a 12% thick NACA 0012 airfoil section. The tests showed that the nose of the bulb tip should not extend beyond the leading edge of the wing. Extending the tip farther forward reduced $C_{L\ max}$ of the wing.

All the bulb tips and end plates tested increased C_D and decreased L/D ratio. This result is due to the following:

1. Poor C_L characteristics of the body of revolution.[8]

[8] R. W. Rainey, "Experimental Determination of Aerodynamic Characteristics of Cylindrical and Spheroidal Bodies of Revolution," (unpublished Master's thesis, Daniel Guggenheim School of Aeronautics, Georgia Institute of Technology, Atlanta, 1948), p. 51.

2. Inherent high velocity and induced angle of attack at the tip of a rectangular wing.[9]

3. Increased skin and form drag of the tips over that of the wing alone.

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[9]Pope, *op. cit.*, p. 13:19.

VI CONCLUSIONS

The bulb tip is less efficient than the plain rounded wing tip over the entire flight range of a rectangular wing. Although the bulb tip may improve the flow over the rectangular wing, the inherent high downwash velocity approaching the tips seems to nullify any action of the tip vortex about the bulb. This velocity q_θ about the bulb is also quite high and tends to be of the same order as the rectangular wing downwash velocity.

In view of the above conclusions and the known downwash patterns of the rectangular and tapered wings,[10] it is believed that this investigation should be extended to include swept back and tapered wings. The velocity q_θ in the case of the tapered wing may tend to increase the downwash velocity at the tip, and in so doing:

1. Improve lift distribution at higher C_L's.
2. Possibly achieve higher wing efficiency with the bulb tip than for the wing alone at some values of C_L.

After the considerable amount of investigation that was done on the rectangular wing it is definitely believed that this work should be carried on through the tapered and swept back wing configurations. This present program was actually Phase I of a program to find out the potentialities of the bulb tip arrangement, and it has determined some criteria that can be used to build on in applying this arrangement to the more practical wing planforms.

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[10] Ibid.

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APPENDIX I

TABLES

TABLE I

PHYSICAL CHARACTERISTICS OF MODELS TESTED

No.	Symbol	d	l	l/d	Description
1.	□	1.25	6.00	4.00	Cyl. with hemispherical nose and conical tail
2.	⬭	1.25	7.00	5.60	Cyl. with hemispherical nose and conical tail
3.	△	0.687	5.50	8.00	Cyl. with hemispherical nose and conical tail
4.	◇	1.25	5.95	4.75	NACA 0021 airfoil of revolution
5.	▽	0.625	5.21	8.34	NACA 0012 airfoil of revolution
6.	○	0.468	5.21	11.1	NACA 0009 airfoil of revolution

NOTE: End plates were cut to conform with the crossectional shape of tips #1 and #3.

TABLE II

AERODYNAMIC CHARACTERISTICS OF WING WITH PLAIN AND BULB TIPS

ASPECT RATIO = 6.84

	Plain Wing Tip			(d = 1.25) Short Cyl. Tip			(d = 0.687) Cyl. Tip			(d = 1.25) 0021 Tip		
	C_L	C_D	L/D	C_L	C_D	L/D	C_L	C_D	L/D	C_L	C_D	L/D
-3	.15	.019	8.0	.15	.021	6.9	.15	.018	8.1	.13	.019	7.0
-1	.30	.019	16.0	.31	.022	13.9	.31	.019	16.3	.29	.019	15.0
1	.47	.021	22.4	.47	.029	16.4	.49	.024	20.4	.45	.023	19.0
3	.61	.029	21.2	.62	.037	16.9	.64	.034	18.9	.58	.032	18.1
5	.77	.039	19.4	.79	.049	16.1	.81	.046	17.5	.74	.044	16.8
7	.94	.055	17.1	.96	.066	14.5	.98	.063	15.5	.92	.062	14.8
9	1.10	.072	15.2	1.11	——	——	1.14	.081	14.1	1.06	.079	13.4
11	1.18	——	——	1.19	——	——	1.21	——	——	1.13	——	——
13	1.22	——	——	1.20	——	——	1.22	——	——	1.15	——	——

TABLE III

AERODYNAMIC CHARACTERISTICS OF WING WITH PLAIN AND BULB TIPS

ASPECT RATIO = 6.84

	(d = 0.625) 0012 Tip			(d = 0.469) 0009 Tip			1.25 End Plate			0.687 End Plate		
	C_L	C_D	L/D	C_L	C_D	L/D	C_L	C_D	L/D	C_L	C_D	L/D
-3	.14	.017	8.2	.15	.019	7.9	—	—	—	.17	.021	7.8
-1	.29	.019	15.6	.29	.019	15.6	.30	.021	14.3	.31	.022	14.6
1	.46	.023	20.0	.45	.023	19.3	.47	.026	18.1	.48	.027	17.6
3	.60	.030	20.0	.59	.030	19.7	.61	.032	19.1	.65	.037	17.7
5	.76	.042	18.1	.77	.041	18.9	.77	.044	17.5	.78	.045	17.3
7	.94	.057	16.5	.93	.056	16.6	.95	.058	16.4	.94	.060	15.7
9	1.09	.075	14.5	1.10	—	—	—	—	—	—	—	—
11	1.18	—	—	1.17	—	—	1.17	—	—	—	—	—
13	1.20	—	—	1.20	—	—	1.19	—	—	—	—	—

TABLE IV

AERODYNAMIC CHARACTERISTICS OF WING WITH PLAIN AND BULB TIPS

ASPECT RATIO = 4.83

	Plain Wing Tip			(d = 1.25) Short Cyl. Tip			(d = 0.687) Cyl. Tip			(d = 1.25) 0021 Tip		
	C_L	C_D	L/D	C_L	C_D	L/D	C_L	C_D	L/D	C_L	C_D	L/D
-3	.11	.020	5.5	.10	.023	4.7	.11	.020	5.5	.10	.019	5.3
-1	.22	.018	12.2	.24	.023	10.4	.24	.020	12.0	.23	.020	11.5
1	.38	.022	17.3	.39	.028	14.1	.40	.024	16.7	.37	.023	16.0
3	.51	.028	18.2	.51	.034	15.0	.53	.031	16.9	.49	.030	16.3
5	.66	.040	16.5	.65	.046	14.1	.67	.043	15.6	.63	.040	15.6
7	.81	.055	14.7	.81	.063	12.9	.84	.061	13.8	.77	.057	13.5
9	.96	.072	13.3	.96	___	___	___	___	___	.92	___	___
11	1.11	.093	11.9	1.09	___	___	1.13	.133	___	1.06	___	___
13	1.21	___	___	1.18	___	___	1.21	___	___	1.15	___	___
15	1.21	___	___	1.17	___	___	1.21	___	___	1.15	___	___

TABLE V

AERODYNAMIC CHARACTERISTICS OF WING WITH PLAIN AND BULB TIPS

ASPECT RATIO = 4.83

	(d = 0.625) 0012 Tip			(d = 1.25) Long Cyl. Tip			1.25 End Plate			0.687 End Plate		
	C_L	C_D	L/D	C_L	C_D	L/D	C_L	C_D	L/D	C_L	C_D	L/D
-3	.10	.019	5.5	.11	.025	4.2	.12	.024	5.0	.09	.023	3.9
-1	.22	.019	11.6	.25	.025	9.8	.25	.023	10.8	.21	.023	9.0
1	.38	.023	16.4	.40	.029	13.8	.40	.027	14.6	.36	.024	14.6
3	.51	.030	17.1	.52	.036	14.5	.52	.033	15.4	.48	.029	16.2
5	.66	.040	16.3	.66	.046	14.3	.66	.043	15.5	.63	.041	15.5
7	.81	.057	14.2	.82	.066	12.4	.82	.057	14.3	.77	.052	14.6
9	.96	___	___	.99	.087	11.4	___	___	___	___	___	___
11	1.11	___	___	1.12	.110	10.2	1.11	.102	___	1.08	___	___
13	1.20	___	___	1.20	___	___	1.19	___	___	1.17	___	___
15	___	___	___	___	___	___	1.19	___	___	1.17	___	___

APPENDIX II

FIGURES

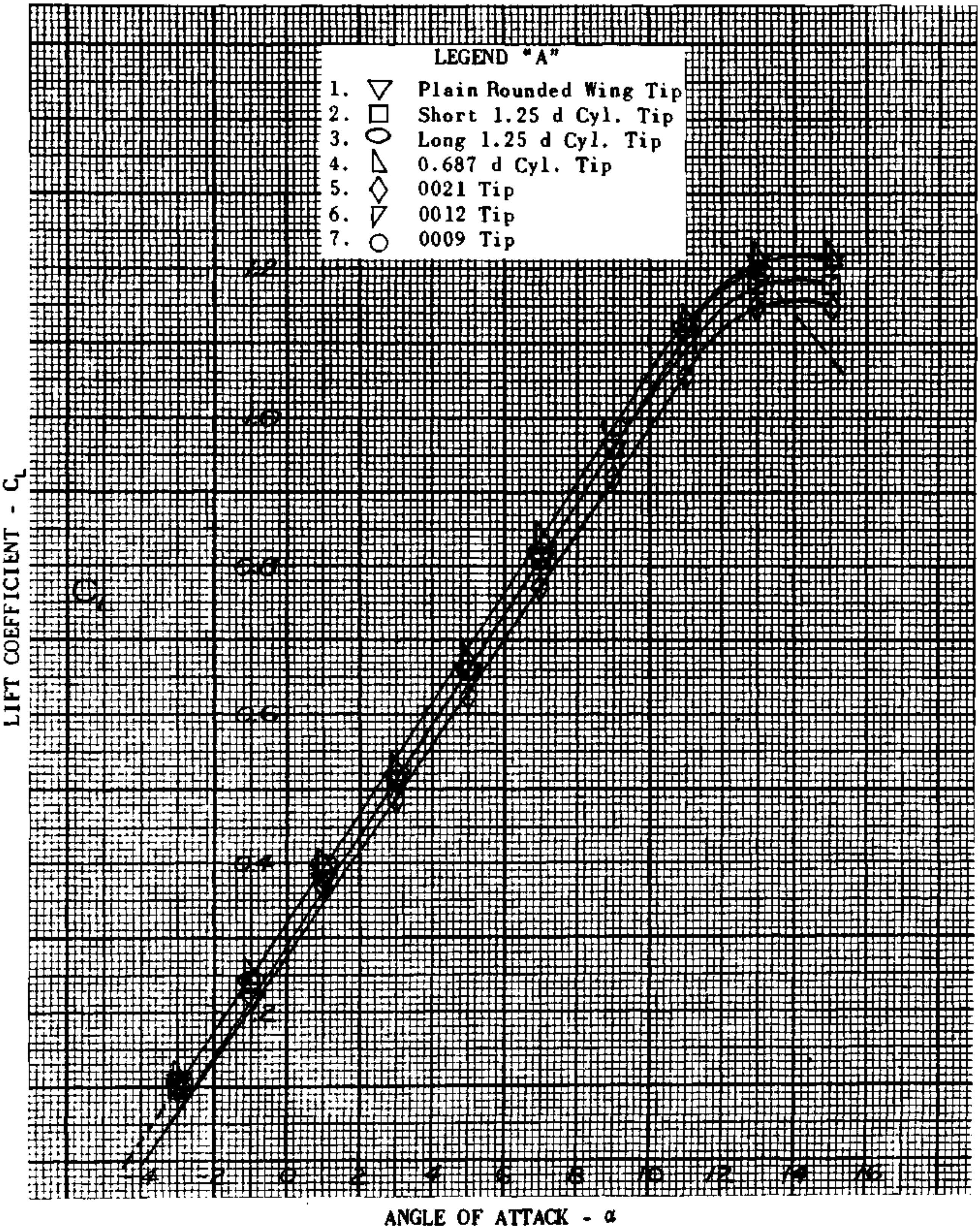

FIGURE 1

WING LIFT COEFFICIENTS FOR VARIOUS
BULB TIPS FOR ASPECT RATIO OF 4.83

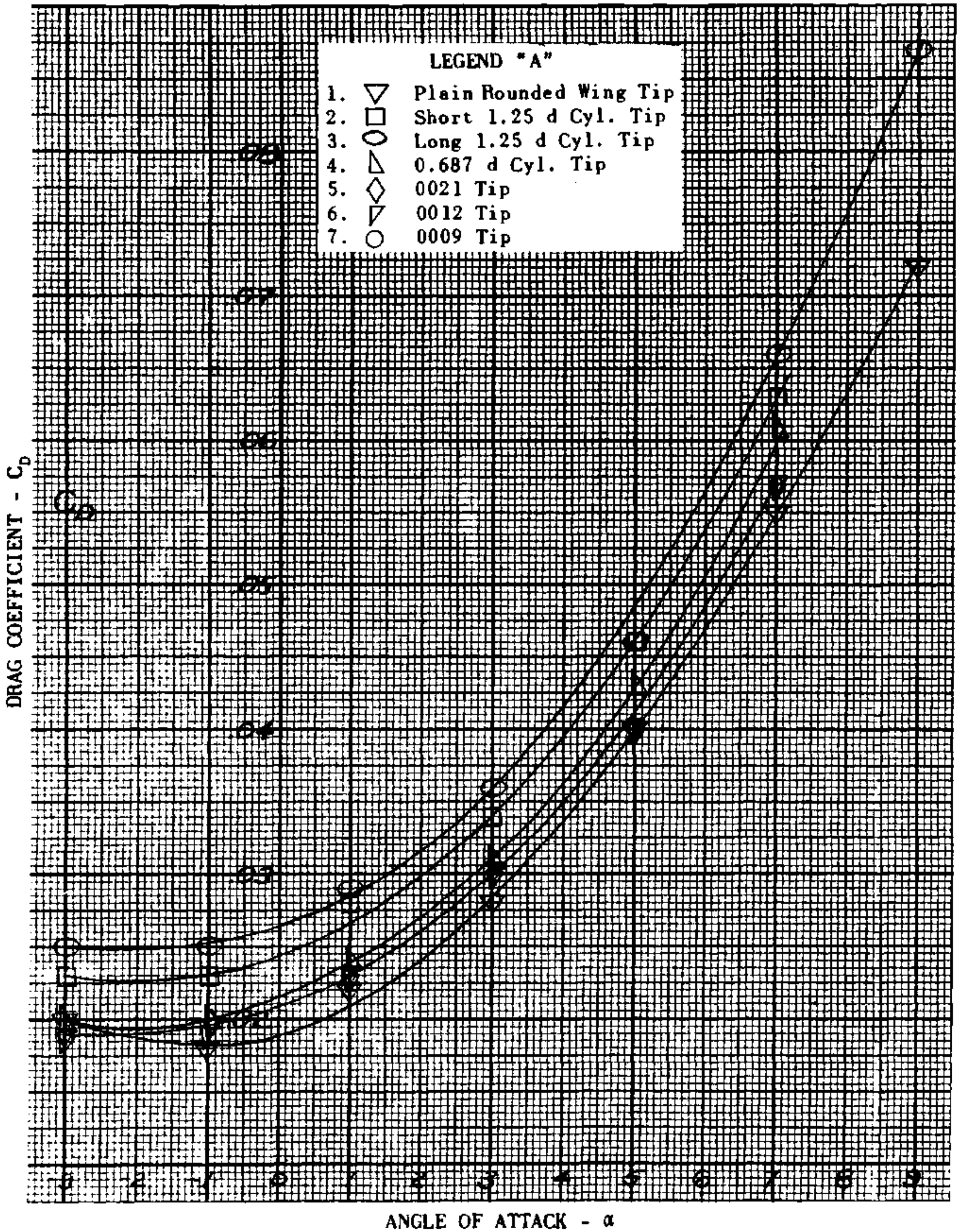

FIGURE 2

WING DRAG COEFFICIENTS FOR VARIOUS
BULB TIPS FOR ASPECT RATIO OF 4.83

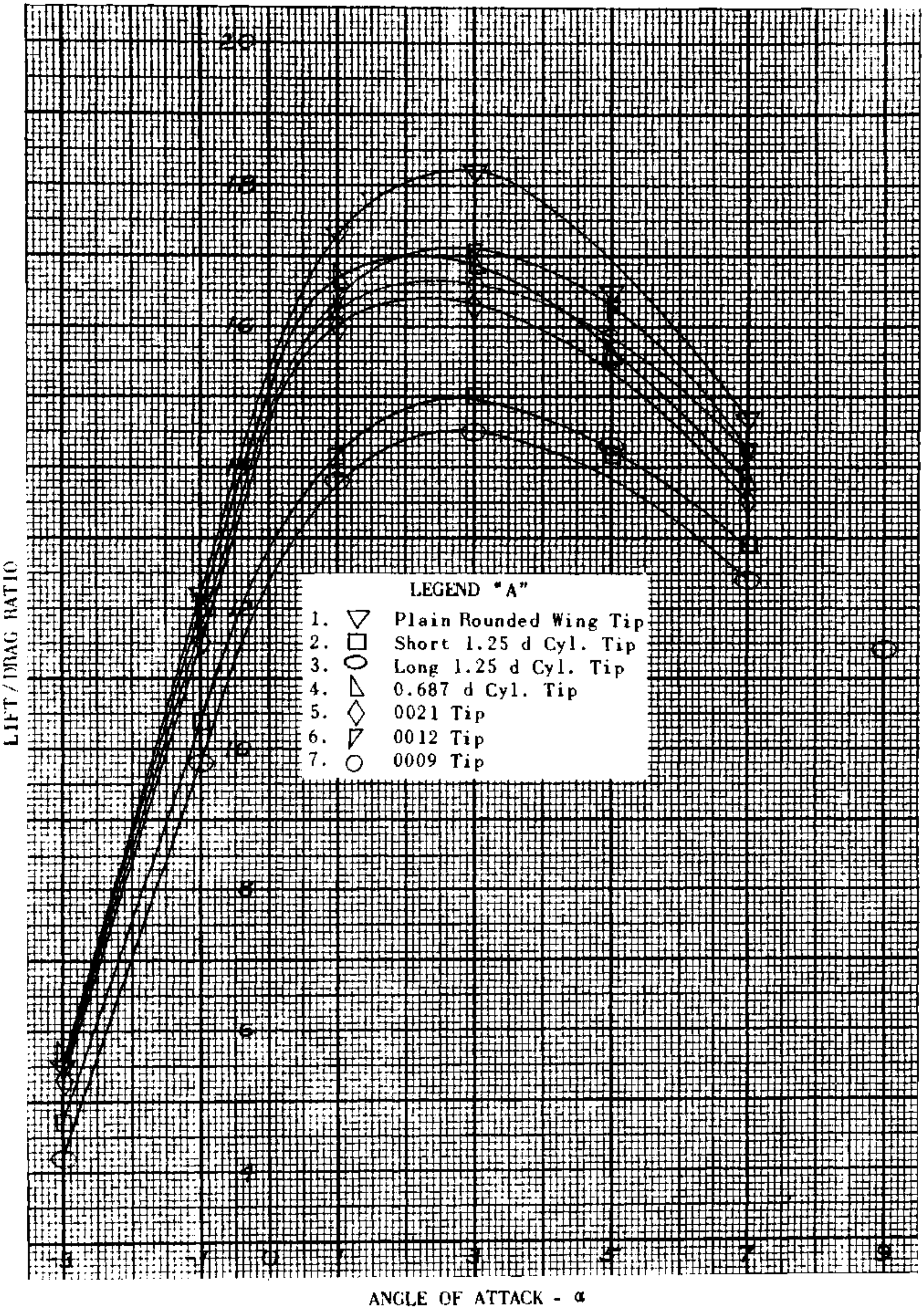

FIGURE 3

WING LIFT/DRAG RATIO FOR VARIOUS
FULL TIPS FOR ASPECT RATIO 4.83

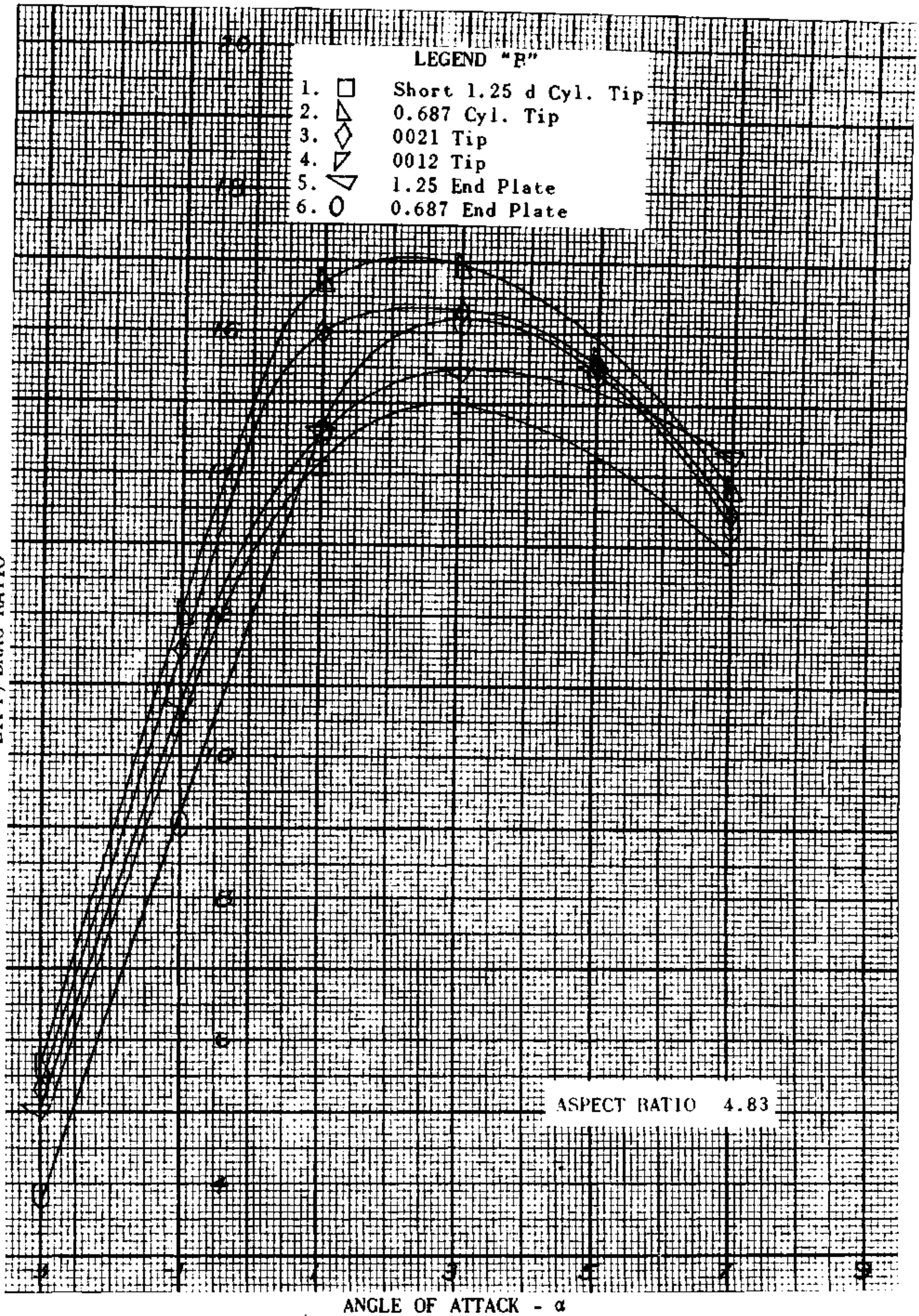

FIGURE 4

COMPARISON OF LIFT / DRAG RATIOS OF BULB TIPS AND EQUIVALENT END PLATES

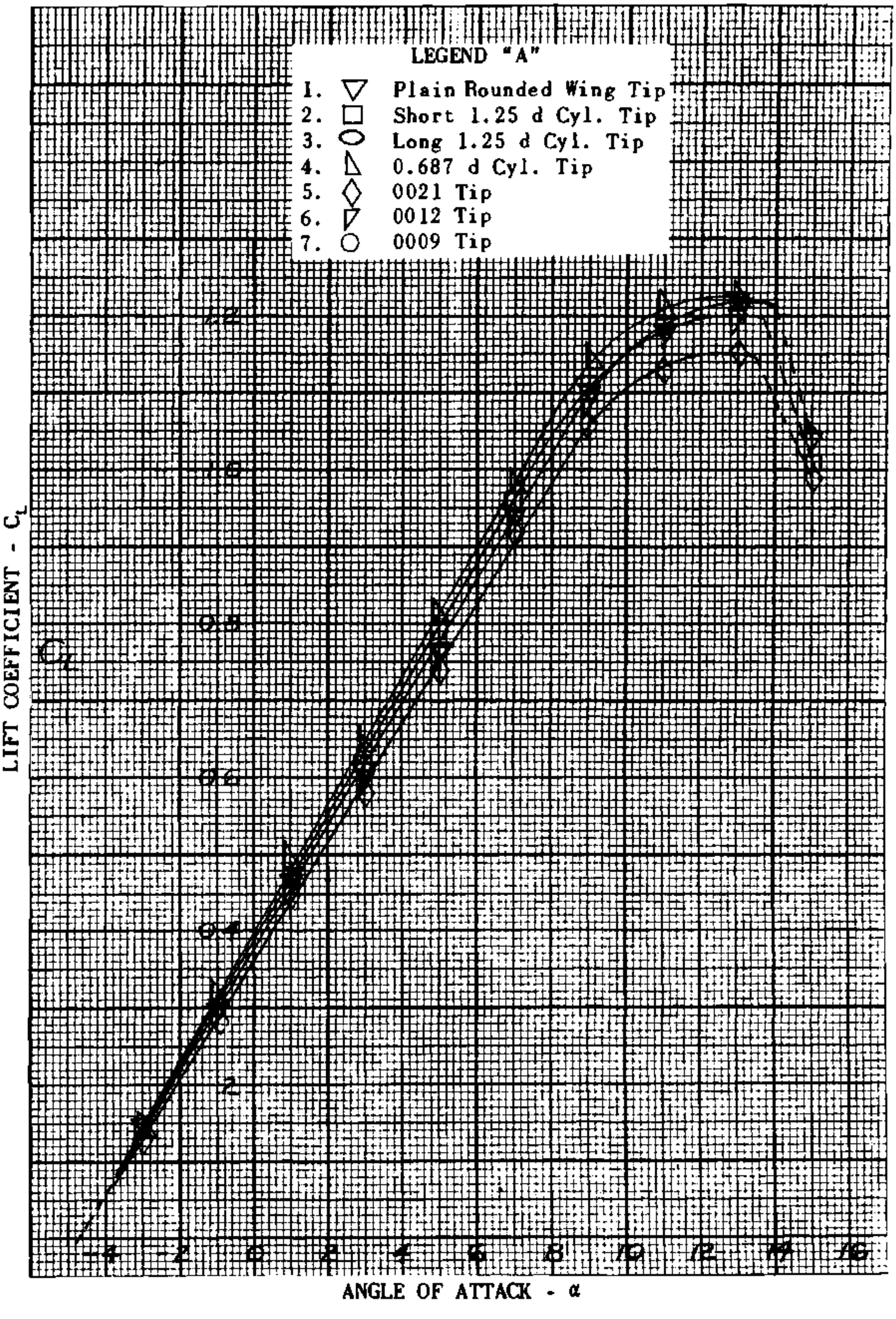

FIGURE 5

WING LIFT COEFFICIENTS FOR VARIOUS
BULB TIPS FOR ASPECT RATIO OF 6.84

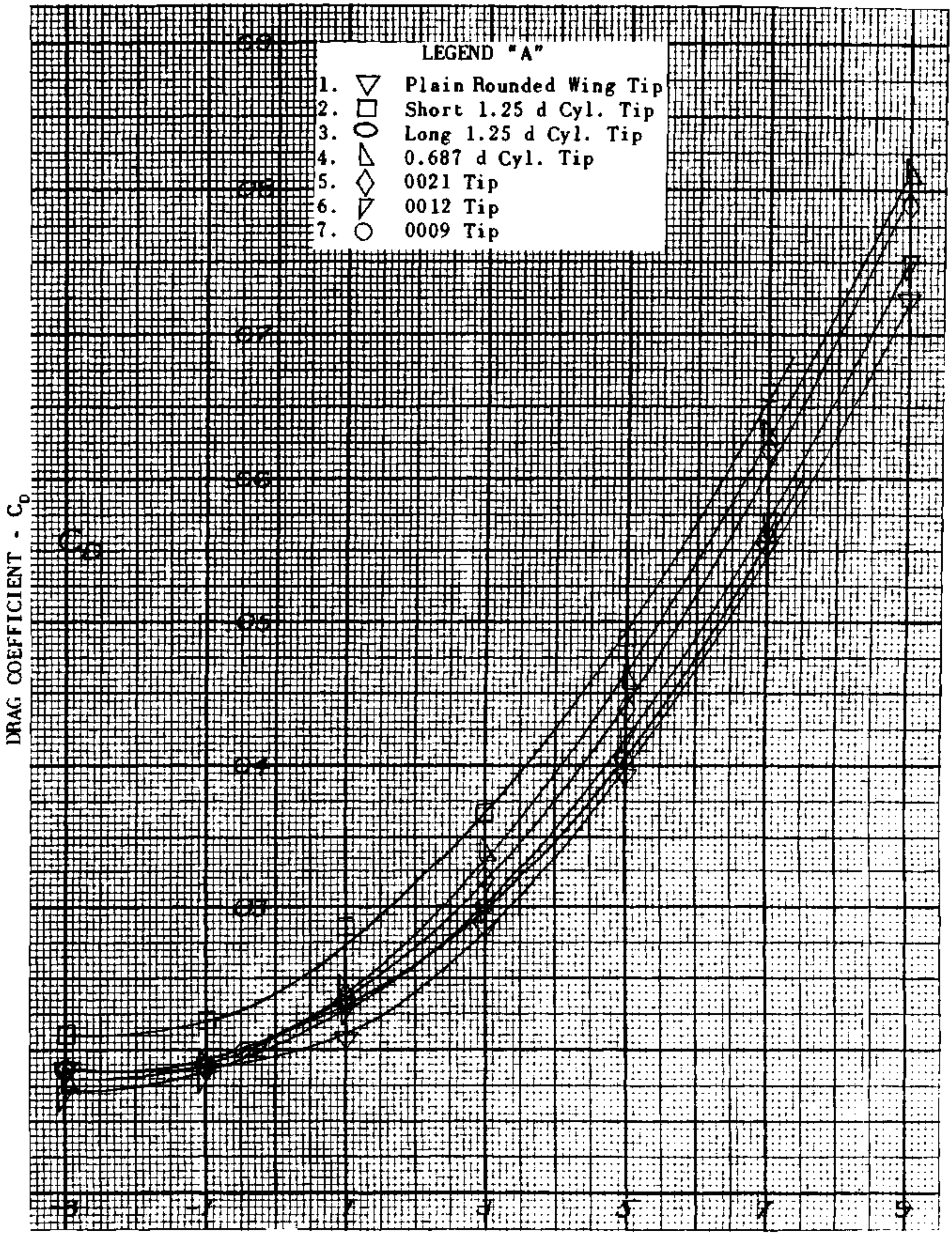

FIGURE 6

WING DRAG COEFFICIENTS FOR VARIOUS
BULB TIPS FOR ASPECT RATIO OF 6.84

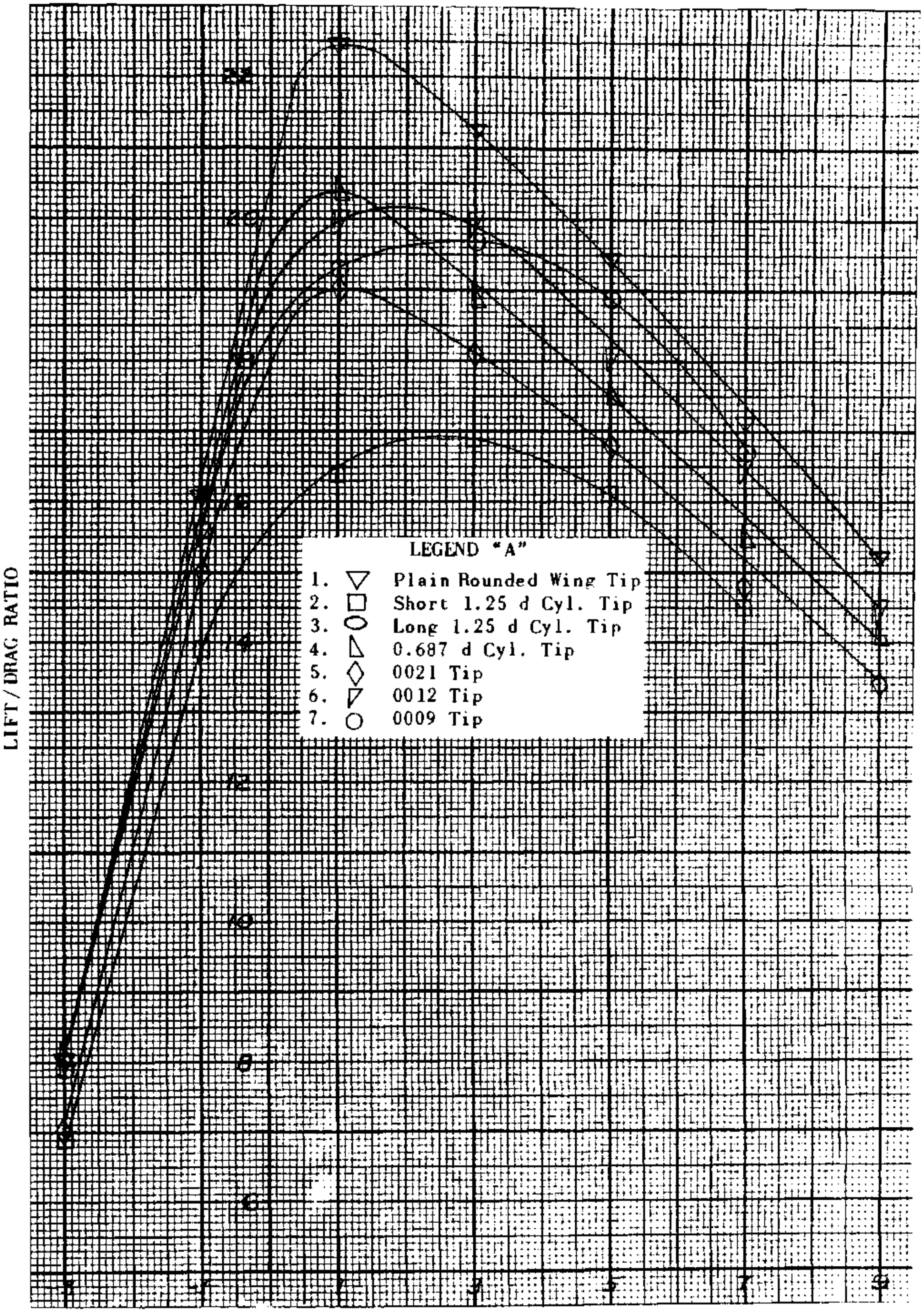

FIGURE 7

WING LIFT / DRAG RATIO FOR VARIOUS
HULL TIPS FOR ASPECT RATIO 6.84

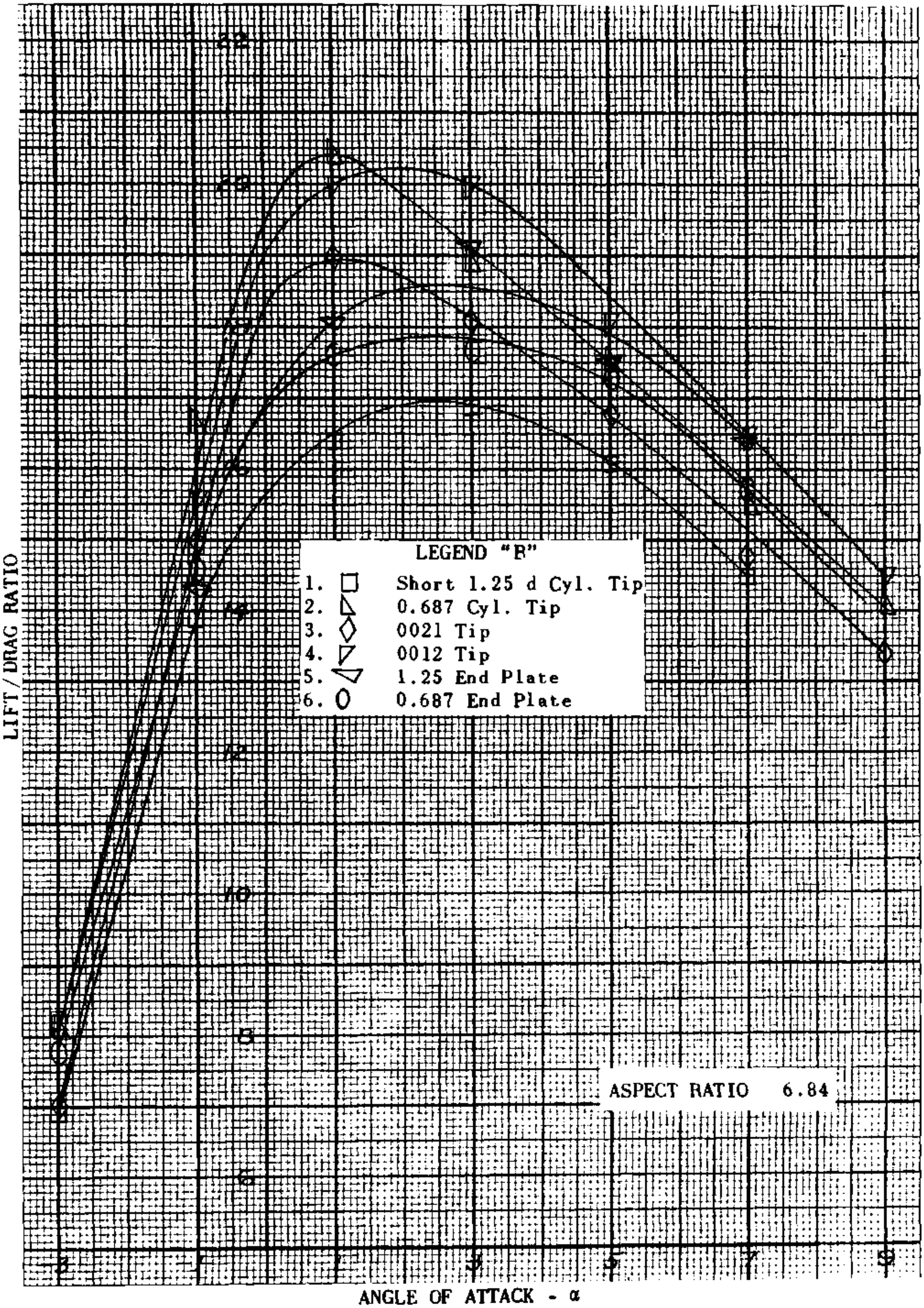

FIGURE 8

COMPARISON OF LIFT / DRAG RATIOS OF BULB TIPS AND EQUIVALENT END PLATES

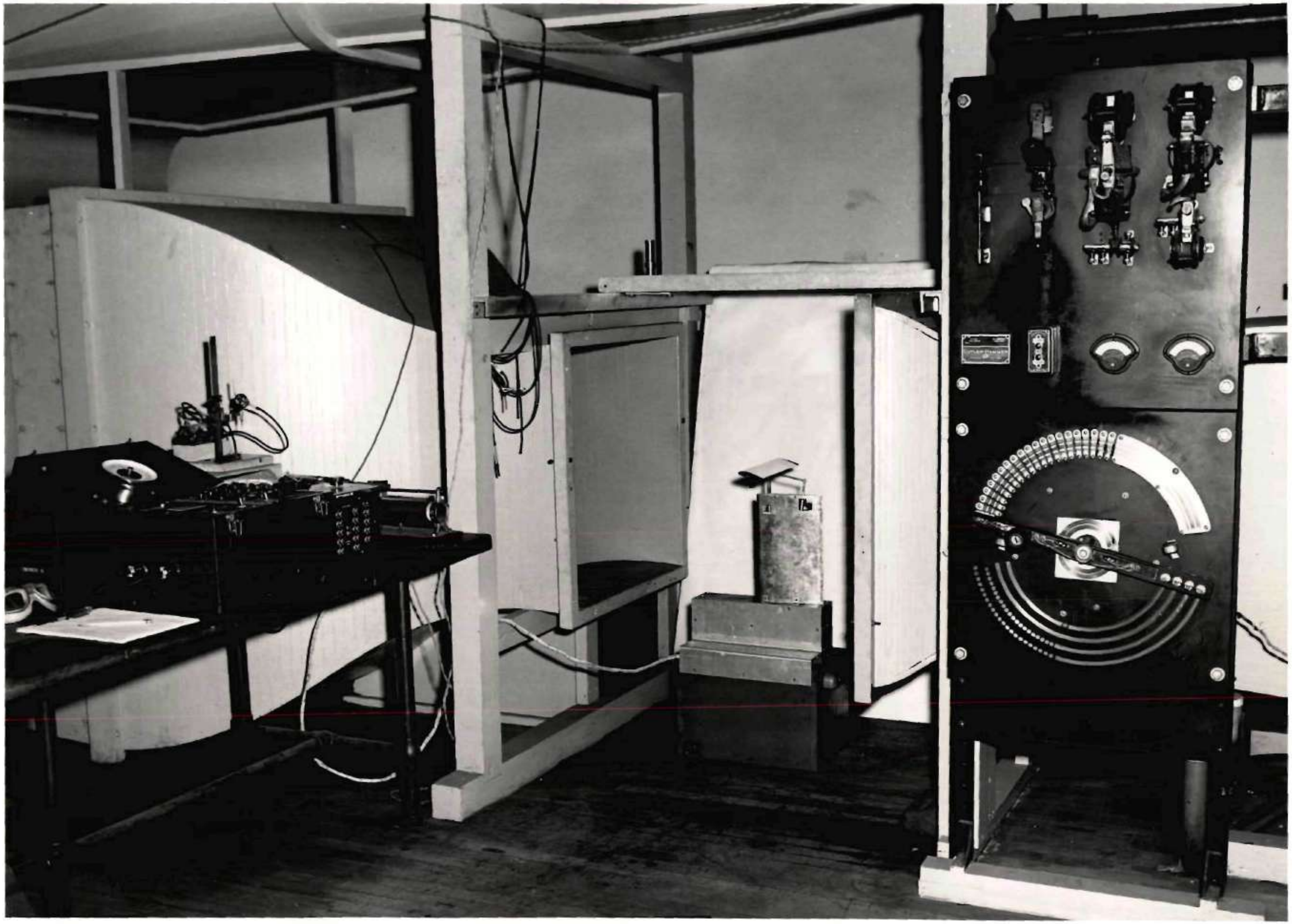

FIGURE 9. TEST SECTION AND APPARATUS

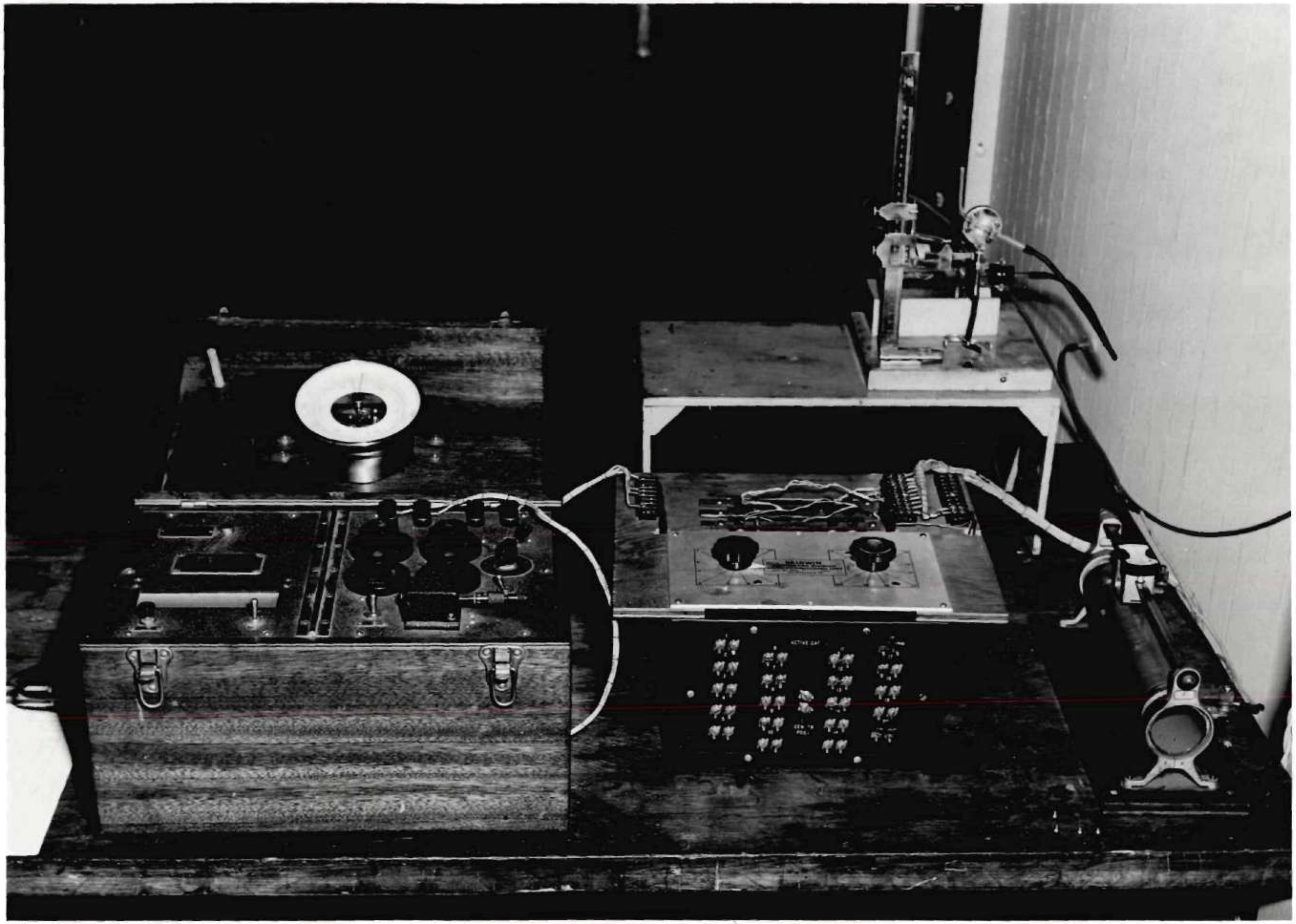

FIGURE 10. CONTROL AND INDICATING APPARATUS

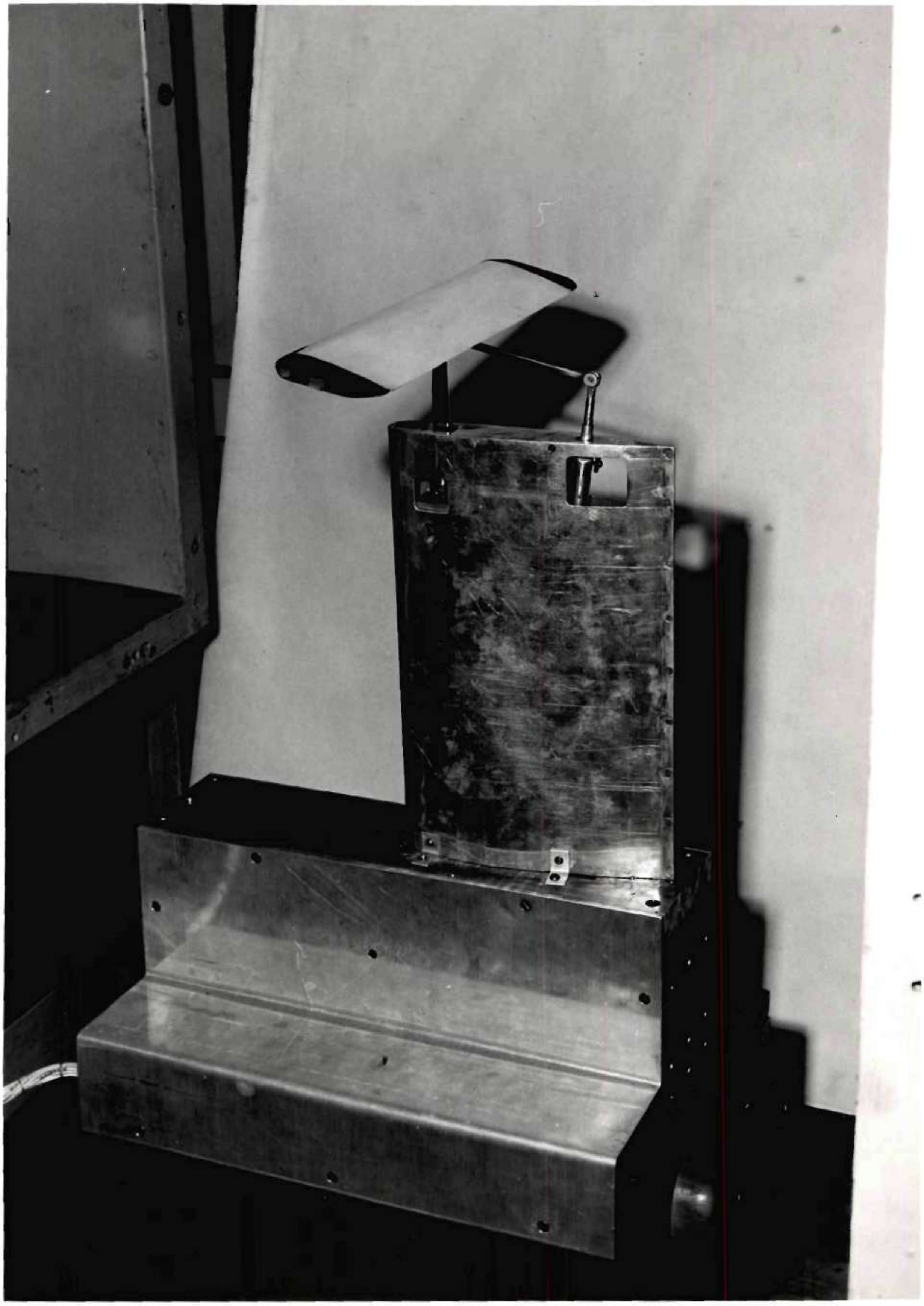

FIGURE 11. PLAIN TIP INSTALATION

FIGURE 12. SHORT 1.25 D CYLINDRICAL BULB TIPS

FIGURE 13. LONG 1.25 D CYLINDRICAL BULB TIPS

FIGURE 14. 0.687 D CYLINDRICAL BULB TIPS

FIGURE 15. N A C A 0021 AIRFOIL TIP

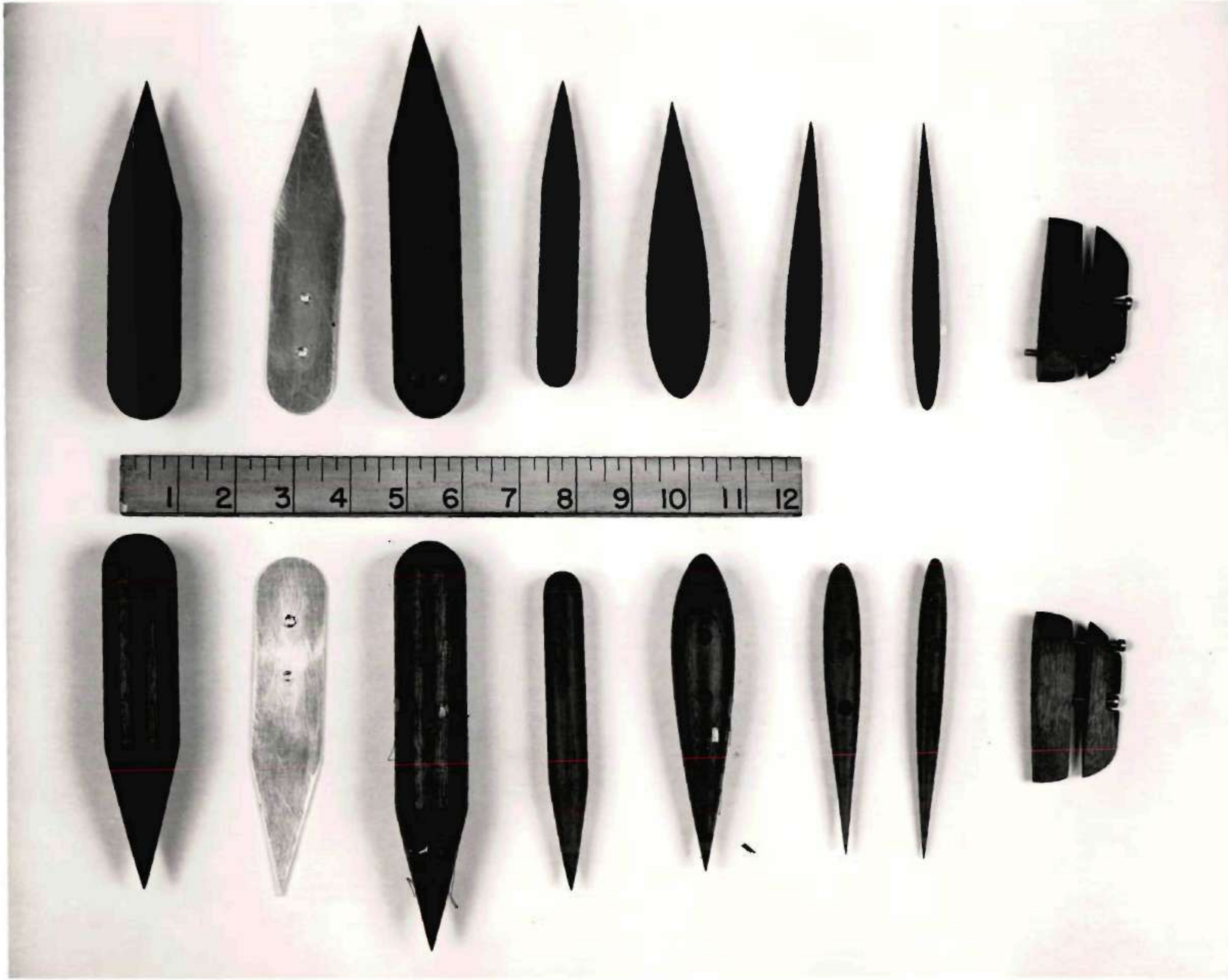

FIGURE 16. MODELS TESTED